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GENERAL STUDY OF LIGHT PLANE SPIN, AFT FUSELAGE GEOMETRY, PART 1

L. Beaurain

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16. Abstract

The effect of aft fuselage geometries on spin is studied in wind tunnel tests on a model. The geometric parameters studied are: shape of the fuselage frame, fuselage width, fuselage length and size of the vertical stabilizer. While the shape of the fuselage frame can have a very strong effect on the type of spin, the effect of the width and length parameters is only moderate. The results of testing different vertical stabilizer sizes were surprising: reducing the size of the vertical stabilizer often had a beneficial effect on spin.

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GENERAL STUDY OF LIGHT PLANE SPIN, AFT FUSELAGE GEOMETRY, PART 1

L. Beaurain

The present report concerns studies requested by the S.T.Aé [Service technique de l'aéronautique (Technical Aeronautic Service)] in order No. 34, lot No. 9, contract No. 73-98413. It concerns the first phase of tests of a general study with regard to light plane spin. /4*

In the course of these tests it was necessary to study the effect on spin of three parameters involving the geometry of the aft fuselage of the air frame, namely:

-the contour of the fuselage frame

-the width of the fuselage

-the length of the fuselage.

Under the circumstances the findings led us to investigate a fourth parameter:

-the size of the vertical stabilizer.

These tests revealed that some of these parameters have a very appreciable effect. On the basis of the conclusions obtained it would be desirable to continue the study into a second phase, the aim of which would be to study the following parameters:

-longitudinal position of the horizontal stabilizers and the vertical stabilizer

-height setting of the horizontal stabilizer.

* Numbers in the margin indicate pagination in the foreign text. There is no page three in the original.

1 - GENERAL REMARKS

1.1 - Purpose

Wind tunnel experiments on light plane spin have shown that /5
the geometry of the aft of the plane often has an appreciable effect. Thus when a problem occurs on a model of a given plane the spin can often be improved by modifying a component of the aft portion of the model such as the fuselage, vertical stabilizer, or horizontal stabilizer.

On the basis of all the findings of wind tunnel spin studies on light plane models it was therefore possible to establish certain rules. All the same it remains that:

-on the one hand the effect of certain changes, which a priori seemed like they might be very beneficial, is in fact not evident and

-on the other hand the original geometry of the plane is sometimes such that important modifications made on the model (and moreover not realistic for the plane) do not result in the sufficient improvement wished for.

The present study brings about some interesting initial conclusions on these two points. Taken as a whole the results of the study, although incomplete, might already be very useful to the aircraft manufacturer for designing a plane with the greatest possibility of having a safe amount of spin.

1.2 - Layout of the Report

The report consists of two main parts. Part one, the present section, deals with general questions. It defines the base model and the modifications which were done to it, lists the tests performed, describes the way in which the results are presented, etc.

Part two of the report deals with the findings. These are presented according to the following plan:

- overall view of the results
- effect of control surfaces
- effect of parameters initially intended to be studied, /6
  namely: the form of the fuselage frame
  the width of the fuselage
  the length of the fuselage
- the effect of the parameter which appeared worthwhile to investigate based on the initial results,
  namely: the dimensions of the vertical stabilizer
- diverse tests.

1.3 - Design of the Model

The photograph in plate 1 and the plans in plate two show the model used and its stationary elements.

Concerning the basic model, and as the left half of plate 2 shows, this is a simple model which might represent a typical plane on a 1:10 scale for a unique case of loading, namely:

900 kg

25%

$I_{xx} = 1000\ m^2kg$

$I_{yy} = 1400\ m^2kg$

The model does not have adjustable flaps or landing gear. It is not equipped with a radio device to operate the control surfaces in flight. The deflections of the control surfaces studied are:

- S/B rudder: 0° and ± 25°
- S/B elevator: 0° and ± 25°
- ailerons: 0° and -15° +10° in each direction.

After the first series of tests, it appeared desirable for the remainder of the study to place a fin beneath the aft fuselage.

The geometry of the wings and fuselage in front of the trailing edge of the wing cannot be modified, nor can the vertical stabilizer or the horizontal stabilizers. The trailing edge of the vertical stabilizer and the horizontal stabilizers is always in the vertical plane at the extreme aft of the fuselage no matter which fuselage is being tested.

The basic fuselage frame is of a simple design, in the present case a square design. Starting with this shape we have modified the section of the fuselage in three ways:

gradual rounding	to obtain the shape of a	see sections plate 2
1) the four corners	circle	2, 3, 4
2) the upper corners	upper semi-circle lower semi-square	5, 6, 7
3) the lower corners	upper semi-square lower semi-circle	8, 9, 10

/7

The test program then called for the setting up of fuselages both longer and shorter and wider and narrower than the basic fuselages. These modifications were done on three frame designs selected on the basis of the findings concerning the effect of the shape of the frames. The frames thus retained were 1, 7 and 10. The right half of plate 2 specifies the various fuselage lengths and widths which were tested.

Thus a total of 22 aft fuselage geometries were constructed.

The present section of the study concludes with tests in which we varried the dimensions of the vertical stabilizer, and for the limiting case the vertical stabilizer was removed. The test conditions as well as the reasons which led us to do these tests will be discussed in detail in section 2.6 where the results of this phase of the tests are given.

Of all the possibilities described in the present section it turns out that the modification of certain shapes led us to study non-realistic geometries. This is something which is currently being investigated in a general manner.

1.4 - List of Tests Performed

More than 500 model launchings were done for the present study. These were exclusively belly spin launchings.

For each of the 22 fuselage geometries 15 combinations of control surface deflections were tested, namely:

Rudder	Elevator	Ailerons
Full width	Full nose-up	Full against and full with
	Neutral	Neutral
	Full dive	Full against and full with
Neutral	"	"
Full against	"	"

/8

this allowed us to approximately define the range of control surface where spin is maintained and where it is stopped.

In the case of a combination of pro-spin control surface the model is often launched giving it two types of spin in succession: relatively slow dive spin followed by rapid flat spin.

It is then observed whether the model remains in the spin applied or, on the contrary, changes towards another type of spin.

In the absence of remote control, in order to obtain the most precise information possible on pull out we proceeded in the following way:

For a given fuselage geometry, with control surfaces deflected for pull out, the model is launched in a spin with a longitudinal attitude and rotation rate similar to the attitude and rotation of spin with the least amount of dive for this geometry. The duration of the pull out is thus defined on the basis of this spin.

The tests using various vertical stabilizer geometries were more succinct, often limited as far as the control surfaces are concerned to the following combinations:

-rudder and elevator set at neutral

-ailerons against and with.

1.5 - Presentation of the Results

All of the results are presented in the plates found at the end of the report in the form of tables or graphs.

Plate 3 is based on all of the findings of the study. It provides information on spin on the one hand and on pull out on the other.

Plate 4 covers all the test results relating to the effect of the shape of the aft fuselage frame. Each column contains three blocks of squares, one block for each deflection setting of the rudder. Finally, each of the squares within a block represents a combination of elevator-aileron deflections. /9

The symbols used in plate 4 clearly indicate
- the range of spins and the range of spin stopages
- the nature of the spins
- the duration of the pull out.

Plates 5 and 6, which are based on the findings of plate 4, among other things classify the geometries according to their spin tendency.

Following the same format as in plate 4, plates 7 and 8 arrange the findings obtained with the wider and narrower fuselage (plate 7) and the longer and shorter fuselage (plate 8).

Plate 9 is like plate 5. It classifies the geometries according to their spin tendency for wider and narrower fuselages and longer and shorter fuselages.

Plate 10 provides the initial results concerning the modifications made to the vertical stabilizer. These were in fact tests "with a normal vertical stabilizer" and "without a vertical stabilizer."

Plate 11 gives the results obtained for various vertical stabilizer dimensions and for a unique fuselage geometry. This type of test was then redone for other shapes of the fuselage section. The results are then presented in plate 12. Finally, plate 13 gives the main findings of plate 12 but in the form of a graph.

1.6 - Various Observations

Before presenting the findings it would appear helpful to recall certain points or discuss them more closely.

a - Rudder and ailerons are said to be "With" or "Against" when they are deflected "For" or "Against" a turn in the same direction as the spin. In the tables of findings "With" and "Against" are understood as "Full with" and "Full against."

b-The rotation rates are given on an aircraft scale. /10

c-In a specific spin study with a given plane it is our custom to divide the phenomena into three groups:

- -stationary spin, i.e. that which persists
- -slowly unstable spin, i.e. spin which progresses toward a stoping point but at a rate which is to slow for the phenomena to be classified as a good pull out
- -rapidly unstable spin, i.e. good pull out.

In a general study simplifying the results by retaining only two groups of phenomena did not seem to cause any problems. The phenomena looked at were permanent spin and spin which comes to a stop no matter how long the pull out time.

d-The characteristics of the spins and the pull outs given in the tables of findings were determined on the basis of test films.

2 - Results /11

2.1 - Preliminary Remarks

Before describing the effect of the various geometric parameters we will cover in the following section certain points relevant to all of the results. These points are the following

- -certain characteristics of the spin
- -the spin pull out
- -the effect of the control surfaces
- -pro-spin and anti-spin effects.

2.2 - General Description of the Results

2.2.1 - Spins

Even if various types of spins were obtained in this study we can still state that the main feature diferentiating these spins is the longitudinal attitude. In most cases other spin characteristics vary only silghtly. Thus:

a) the spins are for the most part calm, i.e. without any agitation (this is the case for most light plane spins); only certain dive spins have an irregular rotation;

b) very often the spins are rapid: <2.5 s/rev. As the upper graph of plate 3 shows:

-the flat spins ($/\Theta/ \approx 20°$) are very rapid ≈ 1.5 s/rev

-the moderate dive spins ($/\Theta/ \approx 40°$) are rather rapid ≈ 2 s/rev

-the dive spins ($/\Theta/ \approx 60°$) on average are rather rapid ≈ 2 s/rev;

c) the span is close to the horizontal except for a few dive spins where the leading wing is raised about 10°;

d) the spin radius is very often small, indeed 0. In fact, the faster the spin the smaller the radius.

2.2.2 - Spin Pull Outs

With regard to the spin pull out the lower graph of plate 3 shows that the flatter the stationary spin (on the basis of which /12 the pull out is obtained) the longer the pull out time.

2.2.3 - Effect of Control Surfaces

As for the control surfaces we found that they behave in the manner often found in other studies, namely:

-rudder "With": pro-spin

-ailerons "Against": pro-spin.

As for the elevator, its effect can change sign depending on the circumstances. Thus for flat spins control column forward is often pro-spin, and for dive spins control column forward is often anti-spin.

2.2.4 - Deffinition of the Terms Pro-Spin and Anti-Spin

From all of the results of the study it turns out that when a fuselage parameter has a pro-spin effect this effect is often characterized simultaneously by:

-an increase in the range of control surfaces where the spin is stationary,

-a leveling out of the spin,

-longer pull out times.

The opposite applies to the anti-spin effect.

2.3 - Effect of the Frame Shape

See plates 4, 5 and 6.

2.3.1 - General Review of the Findings

In the first place the results included in plate 4 indicate that the shape of the aft fuselage frame has a very marked effect on the range of the control surfaces in which spin is maintained.

Thus:

-in one extreme case the spin is stationary over the entire range of the control surfaces, in other words no operation of the control surfaces can stop the spin;

-in another extreme case the pull out is effected over almost the entire range of the control surfaces.

As has already been pointed out, the flatest spins and the longest pull outs (when they exist) correspond to the broadest ranges of spin. Conversely, when for a given geometry the only spins maintained are diving spins, these spins are maintained only in a small range of the control surfaces and outside of this range the spin stops in many cases rapidly. For the basic model (square shape 1) the range of the control surfaces in which the spin persists is greater than half of the total range of the control surfaces (9 stationary spins, 6 stops). The stationary spins are flat, moderately diving or diving depending on the control surfaces. /13

2.3.2 - Transition from the Basic Shape 1 to the circle shape 4

If we start with the basic shape and around the four corners of the section, we observe an anti-spin effect which is all the more pronounced the greater the degree of rounding. Thus for the limiting case (the circle) the range of stationary spins becomes less than half of the total range of the control surfaces (6 permanent spins, 9 stops).

2.3.3 - Transition from the Basic Shape 1 to the Upper Rounded, Lower Flat Shape 7

Starting with the square shape and rounding only the other corners we get a pro-spin effect which becomes all the more noticeable with increasing roundness. This pro-spin effect is such that in the limiting case (case 7):

- the spin is maintained throughout the entire range of the control surfaces,
- all the spins are flat,
- nearly all of the flat spins are obtained from a diving spin launch. Thus the flat spin is very easy to obtain.

2.3.4 - Transition from the Basic Shape 1 to the Upper Flat Lower Rounded 10

When only the lower corners of the frame are rounded the spins become more diving and fewer in number. This type of modification thus has an anti-spin effect even for a relatively small amount of rounding. In fact let us compare the results of case 8 to those of the basic case 1:

	Case 1	Case 8
Number of stationary spins	9	5
Number of flat spins	4	0
Number of pull outs in $\leq$ 2 revs.	0	3

/14

For the geometric limiting case, i.e. shape 10, only 3 spins (all of them diving) are maintained for 15 combinations of control surfaces. The range of control surfaces favorable for pull out is thus very large and in this range the spin stoppages are often rapid.

2.3.5 - Various Observations

The graph in plate 5 classifies the 10 frame geometries according to their spin tendency. The same classification is found in plate 6 which takes into consideration (1) the incidence of spins and (2) the possibility of obtaining flat, rapid spins. These various graphs clearly show that the pro-spin effect at the same time means more spins (greater range) and flatter spins.

Along another line in the course of these systematic tests we studied more or less realistic geometries. The frame shapes most often encountered in aircrafts are like those of frames 2-7. For some of them the spin is severe because of the difficulty, indeed the impossibility, of recovery.

In contrast to the "best frames" among those tested are those which are flat on top and rounded on the bottom. This is a geometry which is rarely if ever used.

2.3.6 - Partial Conclusion

Based on the series of tests which have just been discussed it turns out that the shape of the fuselage frames aft of the win ings can have a considerable effect on the spin behavior of the aircraft. In the limiting cases the spin can be either completely uncontrolable (no matter what type of pull out manuveur is attempted) or very easy to control (pull out accomplished using a single control surface). Thus for certain geometries the effect of the control surfaces becomes secondary with respect to the effect of the geometry.

These results alone might already be found to be extemely useful in designing an airplane.

2.4 - Effect of the Width of the Fuselage /15

See plates 7 and 9.

The effect of the width of the fuselage was studied for three different shapes of the fuselage frame, namely:

fuselage 7 : for which the spin persists over the entire range of the control surfaces

fuselage 10 : for which there are very few spins

fuselage 1 : for which the results lie in between those of the two above cases. see plate 4

The effect of the "fuselage thickness" parameter is the same for the three above frame geometries but, on average, this effect is moderate.

When the phenomena are very pronounced, either "pro-spin" (fuselage 7) or "anti-spin" (fuselage 10), they remain pronounced but to a slightly different degree no matter what fuselage width was studied. In fact, the effect of this parameter shows up better in the case of frame 1. In effect if we take into consideration the number of stationary spins obtained for each fuselage width, we have:

-wide fuselage : 11 spins
-normal fuselage : 9 spins
-narrow fuselage : 5 spins.

Narrowing the fuselage thus has an anti-spin ef ect.

In conclusion, even if the effect of the fuselage width is not negligible it is still less than that of the shape of the frame.

All other things being equal, it follows from these results that a tandem two-seater plane is more likely to have better spin characteristics than a side-by-side two-seater plane.

2.5 - Effect of the Length of the Fuselage

See plates 8 and 9.

The results of the tests relating to fuselage length have some points in common with the preceeding section (fuselage width). In particular, the following is found for "length" parameter:

1) the effect of this parameter is the same for the frame geometries tested except for frame 7 where the effect is slight or nonexistent; /16

2) the effect is slight (or nonexistent. see above) for the geometries in which the phenomena are distinctly pro-spin or distinctly anti-spin (geometries 7 and 10);

3) the effect shows up better for geometry 1.

When the effect is not 0, it can be seen from plates 8 and 9 (lower graph) that the longer the fuselage the greater the chances of recovery.

We can however make the same conclusion as was made for the "fuselage width" parameter, namely that the length of the aft fuselage has a much smaller effect on the spin than the shape of the frame.

Note: other observations or conclusions could have been made in this section but it seemed preferable to us to give them later on in this report after having presented all of the findings of the study.

2.6 - Effect of Vertical Stabilizer Dimensions

2.6.1 - Preliminary Remarks

In describing the test findings for various shapes of the aft fuselage frame we saw that this parameter could fundamentally change the character of the spin. Let us recall the findings for the extreme cases:

-a small number of diving spins, hence a very large range of control s 'faces favorable for pull out,

-flat spins maintained throughout the entire range of the control surfaces. (We should point out here that for light planes the spin is flat because it is very rapid; an increase in the rotation rate, due to its effect on the moment of centrifical pitch, tends to flatten the spin.)

It seemed interesting to us to investigate what effect the aft fuselage has on the nature of the spin:

-either directly: due to its own shape the fuselage is "pro-spin" or "anti-spin",

-or indirectly: wake effect of the fuselage on the vertical stabilizer. As an example one could very easily imagine the transformation from a diving spin to a flat spin by removing the vertical stabilizer. /17

Details on this point could be obtained by tests with the model with the vertical stabilizer removed. A series of tests was thus done under these conditions.

Since some results without the vertical stabilizer turned out to be at leastsurprizing, we continued the study by a series of tests with vertical stabilizers of the same shape but varying in size. Finally, a few tests were done with the horizontal stabilizer removed.

The results of these different test phases are given below in cronological order of the tests.

2.6.2 - Model Test without the Vertical Stabilizer

See plate 10.

For each of the 22 aft fuselage frame shapes we did a test under the following conditions:

- -without the vertical stabilizer,
- -ailerons Against (thus pro-spin)
- -control column forward (pro-spin at least in some cases)
- -mass conditions unchanged.

The results were compared with those obtained with the vertical stabilizer set at neutral and for the same positions of the other control surfaces.

Analysis of the results included in plate 10 reveals a certain amount of dispersion with regard to the effect of removing the vertical stabilizer. Thus, depending on the geometries, removing the vertical stabilizer (1) does not have any effect, (2) or causes the spin to dive, or again (3) causes the spin to be maintained in a case where with the vertical stabilizer the spin ceased.

It does not seem that the effect of removing the vertical stabilizer is essentially related to the shape of the fuselage. By contrast, we can state:

	with the vertical stabilizer		without the vertical stabilizer
a	the spins are flat (≈ 20°)	5 times out of 7	they remain flat
b	the spins are in a slight dive (≈ 35°)	8 times out of 8	diving (≈ 50°)
c	no spin	5 times out of 6	a diving spin is maintained

/18

hence for a) no effect

b) anti-spin effect (see section 2.2.4)

c) pro-spin effect.

If the findings for c) and, strictly speaking, a) are not surprising, the same is not true for the b) findings in which the spin without the vertical stabilizer, because it is in a greater dive, is clearly better than the spin with the vertical stabilizer. This point should be investigated in detail.

2.6.3 - Tests with Various Vertical Stabilizers

See plate 11.

In response to the findings obtained without the vertical stabilizer we made a set of 5 vertical stabilizers consisting of 2 which were larger than the original and 3 smaller than the original (see plate 11). These were tested in the following conditions:

- -short fuselage 1 (with this fuselage removing the vertical stabilizer caused the spin to dive, see plate 10 line 4);
- -rudder and elevator set at Neutral
- -ailerons Against (pro-spin) then With (anti-spin) according to the results of plate 8, col. 4
- -mass conditions unchanged.

The findings presented in the upper boxes in plate 11 show that the phenomena are a function of the size of the vertical stabilizer: the larger the stabilizer, the flatter the spins and consequently the longer the pull out times. The "best" result is thus obtained in the case "without the vertical stabilizer." This confirms the findings of the preceeding section.

Another type of test confirmed the advantageous effect of decreasing the size of (read removing) the vertical stabilizer: with the aileron control deflected for pull out, if the model /19 is subjected to a flat, rapid spin, the pull out is accomplished in:

-17 revolutions with the large vertical stabilizer (1, 6S)	
-12 revolutions with the normal vertical stabilizer (S)	see lower graph, plate 11
-6 revolutions without the vertical stabilizer	

As a result of these findings three observations can be made:

a) the effect of the size of the vertical stabilizer as it has just been discussed concerns the established spin. This effect can be completely different for other phases of spin such as the begining of spin.

b) One can imagine that a gradual increase in the size of the vertical stabilizer will sooner or later bring about a reversal in the effect of this parameter. In specific wind tunnel studies on given planes we have sometimes improved the spin by increasing the size of the vertical stabilizer.

c) One could imagine that the results found so far are for a particular case. In other words, a study of the effect of the vertical stabilizer done on other fuselage geometries could perhaps lead to conclusions which differ from those found up to now. For this reason the present study is being continued.

2.6.4 - Tests with Various Vertical Stabilizers for Various Shapes of the Aft Fuselage Frame

See plates 12 and 13.

In light of the results obtained with various vertical stabilizers attached to fuselage 1 it seemed worthwhile to re-do this same type of test with other aft fuselage shapes. We thus chose the following frames:

4 (circular section)
7 (flat below, rounded on top)
10 (rounded on the bottom, flat on top)

for which very different results were obtained (see plate 4).

From these tests it turns out (see plate 12) that starting with the "original vertical stabilizer" /20

for frames	if the size of the vertical stabilizer is increased	if the size of the vertical stabilizer is decreased
4 and 7	we see a slight anti-spin effect	we see and anti-spin effect which is more pronounced the smaller the vertical stabilizer
10	there is no effect	there is no effect except for the case without the vertical stabilizer where the effect is pro-spin

Thus from all of the results obtained with geometries 1, 4, 7 and 10 it follows that:

- the effect of increasing the size of the vertical stabilizer varies depending on the geometry of the fuselage frame
- the effect of decreasing the size of the vertical stabilizer is very often anti-spin

see plate 13

The practical conclusion which can be drawn here is that when one is faced with a spin problem peculiar to a given plane, if in order to solve this problem one considers changing the size of the vertical stabilizer it is not absolutely clear whether the size should be increased or decreased. In any event one must get rid of the notion that increasing the size of the vertical stabilizer in all cases has a beneficial and that decreasing the size of the vertical stabilizer in all cases has an adverse effect.

2.7 - Tests without the Vertical Stabilizer

See plate 12.

During a spin the vertical stabilizer may turn out to be ineffective (it can even have an adverse effect as we have just seen) because it is in the wake of one or more parts of the plane, such as the wings, fuselage, or horizontal stabilizer.

In the course of the present study we investigated the effect of the horizontal stabilizer on the vertical stabilizer by removing the horizontal stabilizer. The conditions in which the tests were done and the results obtained are given in plate 12 (for the findings column 8 is to be compared with column 3).

A comparison of the results with and without the horizontal /21 stabilizer shows that:

a) the spins without the horizontal stabilizer are in all cases slower, sometimes very distinctly slower;

b) removal of the horizontal stabilizer changes only slightly the longitudinal attitude during the spin, and this in spite of the very great lack of dive due to this removal. In fact, this lack of dive is compensated for by a decrease in the effect of the centrifugal pitch moment due to a reduction in the rotation rate.

Thus in the present case the vertical stabilizer is strongly interfered with by a horizontal stabilizer. The problem here is that of the relative position of the horizontal stabilizer and the vertical stabilizer. It is intended to tackle this problem in the next phase of this study.

2.8 - Tests without Either the Vertical Stabilizer or the Horizontal Stabilizer

See plate 12.

The advantage of doing tests minus both the vertical stabilizer and the horizontal stabilizer is that this allows us to find out the unique effect of the aft section of the fuselage by eliminating any possible interference with the aft stabilizers. The last column in plate 12 shows the results of this series of tests.

The nature of the spin minus both horizontal and vertical stabilizers depends strongly on the shape of the aft fuselage frame. Thus, depending on the shape of the frame the spin can be classified as very flat, flat and slightly or moderately diving. If we classify the fuselages according to their spin tendency (taking into account certain observations made in section 2.2.4) we obtain the following classification:

10 4 $\boxed{1}$ 7

pro-spin effect (spins becoming flatter and more rapid)

and we find that for the fuselage geometries in question the above classification is the same as that given in plate 6 for the complete model.

On the basis of these tests it can thus be stated that the geometry of the aft fuselage has a direct effect, because of its particular shape, on the nature of the spin, and this is more pronounced than any indirect effect of the fuselage such as its wake acting on the vertical stabilizer.

2.9 - Various Remarks

Before going on to the conclusion of this study in the present section we will bring together some comments or remarks concerning various points arising in the present case:

- the T D P F (Tail Damping Power Factor)
- possible Reynolds effect in our tests
- foreign findings obtained on the same topic
- some results obtained during the present study
- extrapolation of the results to other aft fuselage geometries
- magnitude of certain spins
- the back spin
- future tests following the present study

2.9.1 - The Tail Damping Power Factor

The Tail Damping Power Factor (TDPF) is a very old empirically defined U.S. criterion, the aim of which is to predict the best possibilities for spin recovery on the basis of certain geometric and mass characteristics of the aircraft: recall that the greater the TDPF value, the greater the chances of good recovery.

In the present study when we varied the geometry of the fuselage frames we did not modify:

- the length of the aft fuselage
- the realtive position of the horizontal stabilizers and the vertical stabilizer
- the mass characteristics of the model

and thus we worked with a constant TDPF.

The findings included in plate 4 reveal that for the same TDPF we can obtain fundamentally different results ranging from completely uncontrolable spin to spin which is very easy to control.

Along another line, the tests done with various vertical stabilizers often revealed that a decrease in the surface area of the vertical stabilizer (and thus also of the rudder) has a beneficial effect. But according to the TDPF the opposite, or at least a zero effect, should have been found.

The conclusions which can be drawn here are similar to some which have already been made in the course of specific studies on given airplanes to find out if the TDPF does not take into account all the parameters (some of which are very influential) which can affect the spin.

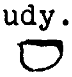
2.9.2 - Reynolds Effect /23

In tests on the spin model, by virtue of the particular dimensions of the model, the Reynolds effect often arises, at least for certain elements which in a first approximation can be likened to portions of a cylinder, such as the fuselage.

Studies abroad (among others NASA TRR29) have shown the very appreciable effect of the Reynolds number on cylinders both of circular and non-circular section. As an example, the Cy may change sign when one passes from the "subcritical rating" ($\mathcal{R} <\approx 0.5\cdot 10^6$) to the "super-critical" rating ($\mathcal{R} >\approx 0.8\cdot 10^6$). Now during a spin the aft fuselage is "subcritical" for the model and "super-critical" for the airplane.

Thus it is possible to imagine that there could exist a Reynolds effect for the spin tests at least with respect to certain fuselage geometries, such as with the bottom of the fuselage more or less rounded. However, it seems a delicate matter to extrapolate from results obtained with very elongated cylinders, not interfered with by other elements and exposed to constant yawing, to a part such as a fuselage in the act of spinning. Even the effect of $\mathcal{R}$ is not always obvious. Numerous good cross-checks between model spins and actual plane spins would lead us to conclude, on the contrary, that the Reynolds effect is often weak in our tests.

2.9.3 - Results of Foreign Studies

In a very old English document (Aeronautical Research Committee - R and M No. 1689 of Nov. 29, 1935) relative to the spin study for various aft fuselage geometries, one of the parameters tested was the section of the fuselage. This study was not very detailed, distinctle less detailed than the present study. The following geometries were among those tested:  and  . Very good agreement was found to exist between the conclusions of these tests and those of the present study with regard to the effect of these two geometries on spin.

2.9.4 - Remarks on Certain Findings of the Present Study

We will consider here some of the results of the present study which present some mutual contradictions.

We saw in section 2.6 that the presence of the vertical stabilizer often had a pro-spin effect. Based on this result /24
one could imagine that decreasing or increasing the length of the fuselage, and thus decreasing or increasing the lever arm of the vertical stabilizer, would have a relative anti-spin and pro-spin

effect respectively. But as plate 8 shows this is not at all the case. Although the fuselage length is not a parameter which has a marked effect on spin, it nevertheless turns out that it behaves in the way which appears most logical, namely that the longer the fuselage the more likely the recovery. It is difficult to provide an explanation to this contradiction without going into the problem in more detail.

Another example still has to do with the effect of the vertical stabilizer:

a) under headings 2.6.3 and 2.6.4 we have seen that the presence of the vertical stabilizer often had a pro-spin effect. On the basis of this one might predict that the rudder would have a zero effect, indeed in the unusual sense.

b) But in the course of the present study we found that the effect of the rudder was the usual effect: With: pro-spin
Against: anti-spin.

The apparent contradiction between a) and b) might be explained in the following manner:

When the spin is sufficiently flat the vertical stabilizer can be considered to be pro-spin. Then of course the rudder cannot stop this spin. In order to make the spin dive the aileron control must be activated, putting it in the "With" position. When the spin is in a sufficient dive the vertical stabilizer (and the rudder) again become effective and the spin can then stopped by operating the rudder. The effectiveness of the rudder also often shows up in plates 4, 7 and 8 where, when diving spins are obtained (either for certain geometries, or for a certain geometry when the ailerons are in the "With" position) these spins are often maintained with the "With" rudder and always stop with the "Against" rudder.

We can thus conclude that the effect of the vertical stabilizer can vary during the same spin in proportion as the spin changes. Thus it has frequently be observed, both in wind tunnel and full scale experiments, that for the same plane the rudder is effective in a diving spin and ineffective in a flat spin.

2.9.5 - Possibility of Extrapolating Certain Results to Other Aft Fuselage Geometries /25

It is obvious that the effect of certain parameters found in the present study can be generalized to all light planes. This is especially the case with regard to the shapes of the fuselage frames. Thus, as an example and proof, all the plane model having a flat-bottomed fuselage (shape 7) tested in the wind tunnel exhibited more or less pronounced spin problems.

By contrast, it would be rash to think that some parameters always have a hard and fast effect. Recall for instance the pro-spin effect when the vertical stabilizer is present. On this point we could cite as examples those cases, rare it is true, where in wind tunnel experiments we decreased the magnitude of spin problems by increasing the surface area of the vertical stabilizer. These results are in contradiction with some findings of the present study.

In fact, we think that the effect of changing the vertical stabilizer depends essentially on the aft geometry of the plane.

On the basis of the tests discussed under heading 2.7 we have seen that for our spin model the vertical stabilizer is strongly interfered with by the horizontal stabilizer. But of course, this interference depends on the relative position of the vertical and horizontal stabilizers. Thus for an extremely forward or extremely aft position of the horizontal stabilizers with respect to the vertical stabilizer, the vertical stabilizer may be relatively well fed and thus effective, and in this case any modification of its surface area could only make it more or less effective by increasing or decreasing its surface area respectively. This observation is confirmed by the following example: in wind tunnel experiments we sometimes reduced the effectiveness of a vertical stabilizer by increasing the surface area of the horizontal stabilizers.

In the subsequent phase of the general study it is intended to investigate in more detail the points mentioned under this heading.

2.9.6 - Remarks Relative to Certain Full Scale Spins

In measuring certain spins for actual planes we have sometimes found that during a "slack controls" manuveur the rudder goes to or remains in the full Against position which is the *a priori* favorable position for recovery, but without in so much as stopping the spin.

In a report dated 1971 concerning the spin of a foreign air- /26
plane for which the above phenomenon had been observed we put forth the following hypothesis:

> "The flow around the vertical stabilizer does not introduce any anti-spin yawing moment by means of the vertical stabilizer. Otherwise this flow should keep the rudder in the 'With' position. The crossing over of this control surface into the 'Against' position even suggests that the rudder is subjected to a pro-spin force".

This assumption is now verified by certain tests in the present study. Thus on the basis of general tests it is sometimes possible to corroborate the existence of phenomena observed during a specific study of a given aircraft. One of the aims of following up the present study would be to provide an explanation of these phenomena.

2.9.7 - Back Spin

The present study was exclusively devoted to belly spin. In the part dealing with the effect of the fuselage frame shape on spin we saw that this parameter had a very large effect in the case of belly spin. We are then justified in thinking that this parameter will have an equally very appreciable effect on back spin. In fact, a strongly "pro-belly spin" could become strongly "anti-back spin" and vice versa. This point deserves being kept in mind in the future.

2.9.8 - Continuation of the Study

The results discussed in this report are those of an initial series of tests which it seems very desirable to continue.

We had considered that the follow up to the study should be devoted to investigating the effect of the following parameters:

- longitudinal position of the vertical stabilizer
- longitudinal position and height setting of the horizontal stabilizers.

The initial findings only confirm the usefulness of the above tests. But in addition it would likewise seem necessary to investigate some points of the present study in more detail. In particular, with visualization tests using wool thread it would probably be possible to find explanations for the at least surprising results which were obtained when we varied the size of /27 the vertical stabilizer. Finally, the back spin tests considered in the preceeding section should also be included.

2.10 - Conclusion

The initial aim of the tests within the scope of the present study was to determine the effect on spin of geometric parameters involving the fuselage aft of the wings. In particular, the following parameters were studied:

- the shape of the fuselage frame
- the width of the fuselage
- the length of the fuselage.

In addition to these parameters the following was also studied:

- the size of the vertical stabilizer.

The geometry of the fuselage frame can have a very strong effect on the nature of the spin. In an extreme case, i.e. with the fuselage rounded on the bottom and flat on top, the spin, always in a dive, can be very easily stopped by a simple manuveur of the control surfaces. In another extreme case, i.e. with the fuselage flat on the bottom and rounded on top, the spin, always flat, is maintained throughout the entire range of the control surfaces. It should be noted that this latter geometry is a relatively common type for airplanes.

The width and length of the fuselage are parameters whose effect is moderate and, in any event, less important than the effect of the shape of the fuselage frame. Often the spin is easier to control when the fuselage is narrower or longer.

The tests with vertical stabilizers of various sizes produced results which were a priori surprising. Decreasing the surface area of the vertical stabilizer (at the limit, removing the vertical stabilizer) very often turned out to be very beneficial. The spin went into a greater dive and as a result of the same became easier to control. It should be possible to explain this phennomenon by means of visualzation tests.

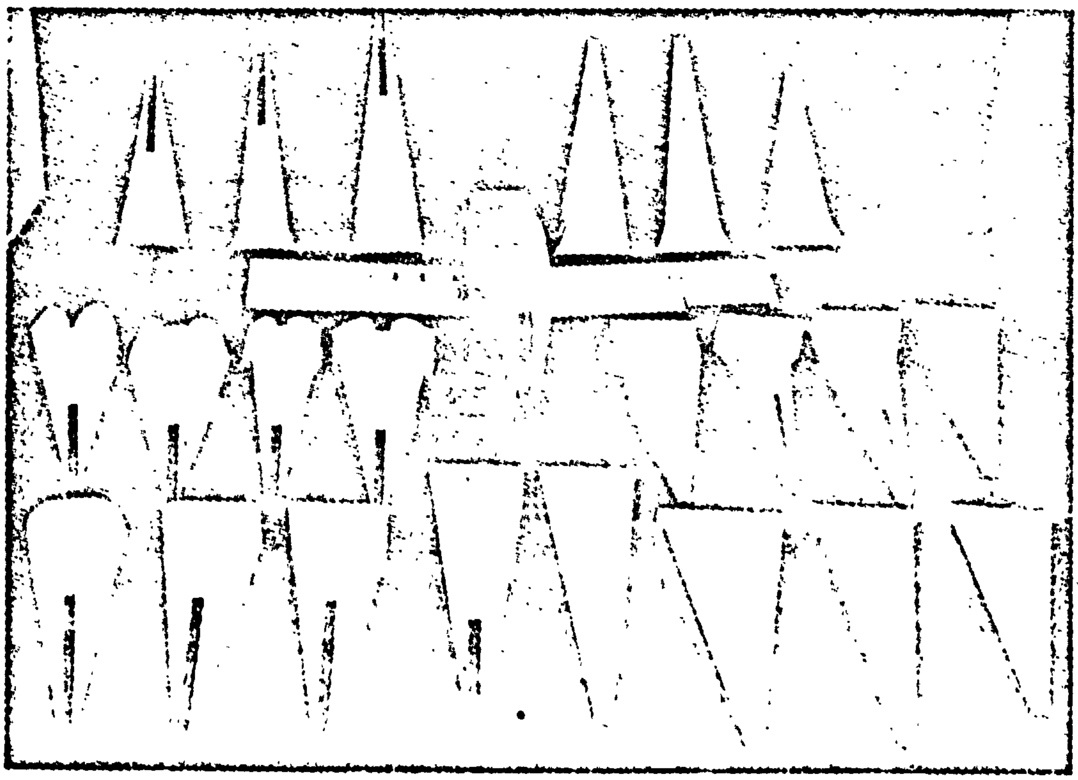
The experiments covered in the present report should be considered as an initial phase of tests of a study which it seems worthwhile to continue. In the follow up one of the first aims would be to investigate to what extent the initial conclusions can be extrapolated because one must anticipate what parameters, /28 other than those studied so far, should likewise have an appreciable effect on spin. One of these new parameters is the relative position of the horizontal stabilizers and the vertical stabilizer. This point is planned for inclusion in the follow up study along with the above mentioned visualization tests. Furthermore, the effect of the geometry of the fuselage frame should be investigated in the case of back spin.

All of the studies will be writen up in a document which will certainly be of interest to aircraft manufacturers.

Finally, we note that the tests already done or planned are limited to "aft fuselage parameters." Thus for the time being "wing" parameters are not taken into consideration.

Plate 1

THE MODEL AND ITS VARIOUS FUSELAGE SHAPES

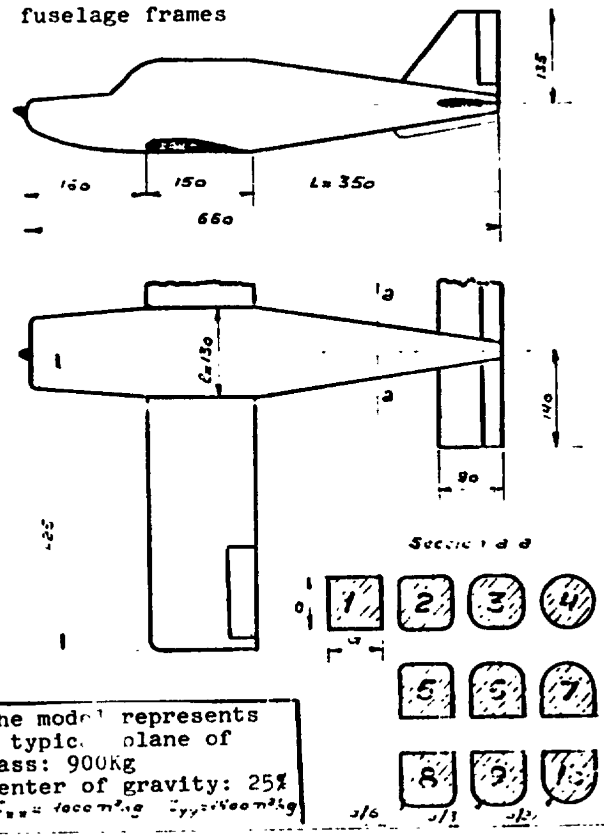


verified

IMFL. Problem — Designed by Beaurain — verified by — Date 11-30-76 — Plate 2

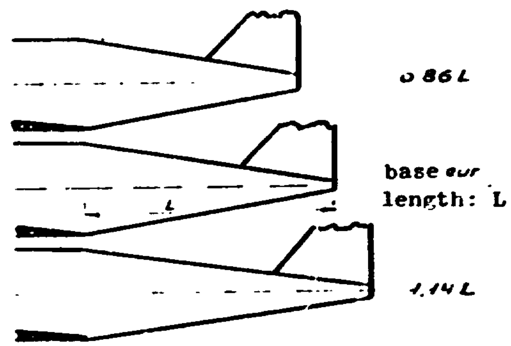
DESIGN OF THE MODEL AND VARIOUS AFT FUSELAGE GEOMETRIES

A-Shape of the aft fuselage frames



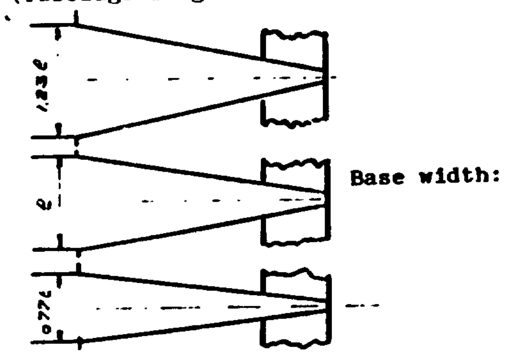
The mode' represents a typic. plane of
mass: 900Kg
center of gravity: 25%

B - Length of the aft fuselage (fuselage width = base width)



Note: modifications B and C were done for 3 frame shapes: 1 7 and 10

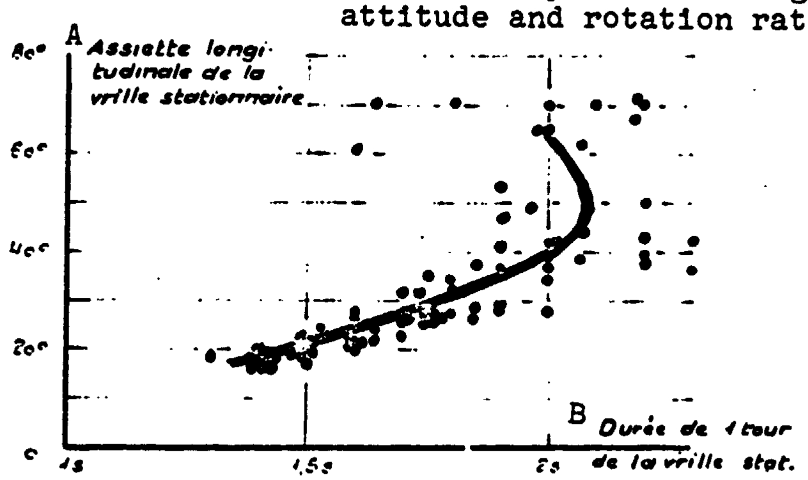
C - Width of the aft fuselage (fuselage length = base length L)



I.M.F.L.	Problém	Designed by	Verified by	Date 1/13/77	Plate 3

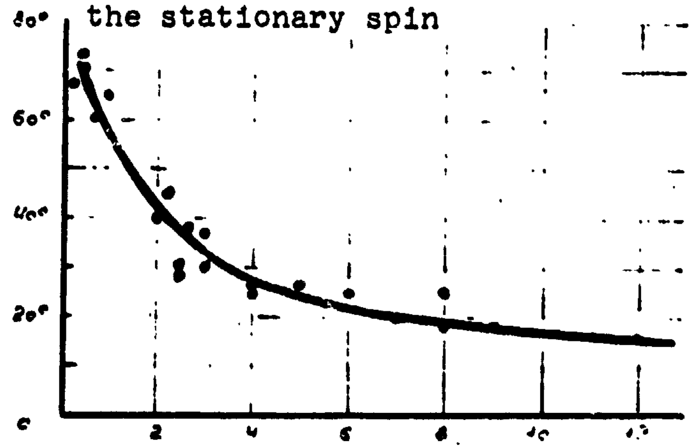
GENERAL REMARKS

REGARDING SPIN: Relationship between longitudinal attitude and rotation rate



REGARDING PULL OUT: Relationship between longitudinal attitude of the spin and the pull out time

Longitudinal attitude of the stationary spin



Pull out time expressed in revolutions (control surfaces set fully for pull out)

A) Longitudinal attitude of the stationary spin

B) Duration of one revolution of the stationary spin

Designed by Verified by

IMFL Plate 4

11/25/76

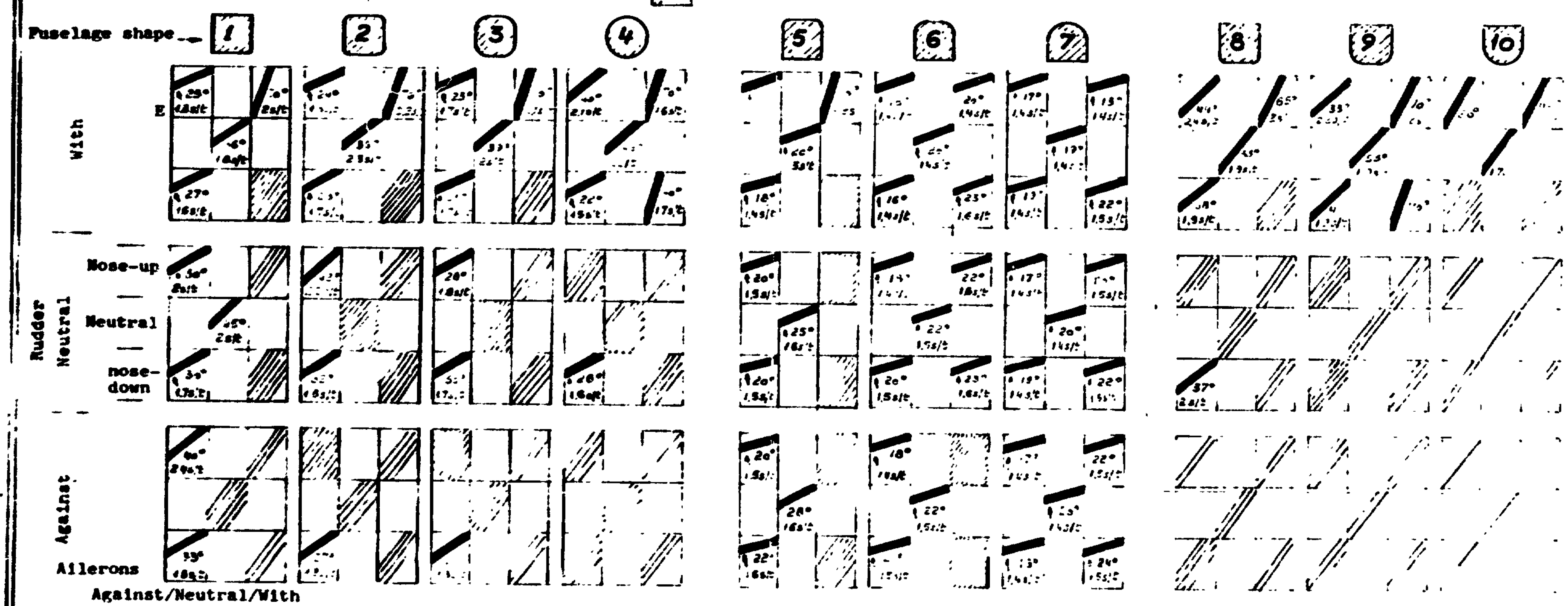
COMPLETE RESULTS OBTAINED FOR THE SIX APT FUSELAGES SHAPES TESTED

A Vrille stationnaire (c.à.d. qui s. perpétue) plus (/) ou moins (—) piqué. Sont portées dans les cases : l'assiette longitudinale la durée de 1 tour (avion)

B La flèche indique que la vrille plate a été obtenue à partir d'un lancer en vrille piquée

C Arrêt de vrille

D Le nombre de lignes correspond, approximativement, au nombre de tours nécessaires pour obtenir l'arrêt



A) Stationary spin (i.e. maintained spin) more (/) or less (/) nose-down. The recorded information indicates: longitudinal attitude the time for 1 revolution (airplane)

B) The arrow indicates that the flat spin was obtained from a nose-down spin launch.

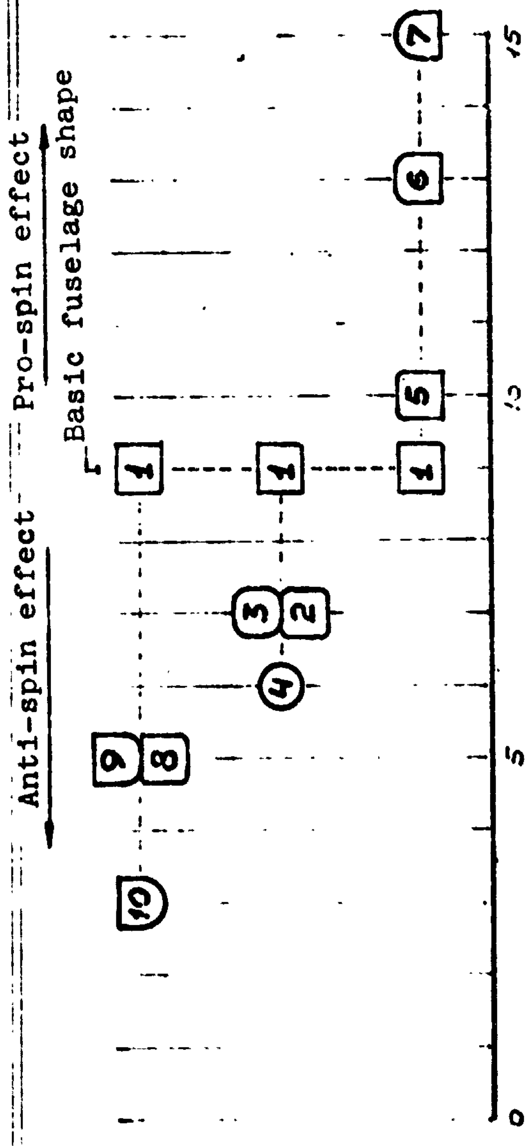
C) Stoppage of spin

D) The number of lines corresponds approzimately to the number of revolutions necessary to obtain stoppage.

E) [s/t = seconds/revolution]

I.M.F.L.	Problem	Designed by	Verified by	Date 11/29/77	Plate 5

CLASSIFICATION OF FUSELAGE SHAPES ACCORDING TO THEIR SPIN TENDENCY



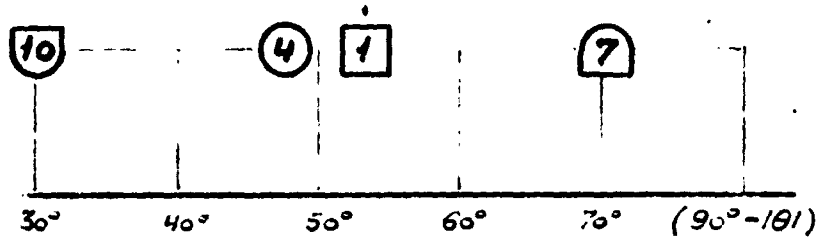
Number of control surface combinations for which the spin is stationary (reminder: for each fuselage 15 combinations are tested)

This plate is based on the results given in plate 4 in which the stationary spins are represented by the symbol (/)

I.M.F.L.	Problem	Designed by	Verified by	Date	Plate 6
				11/29/76	

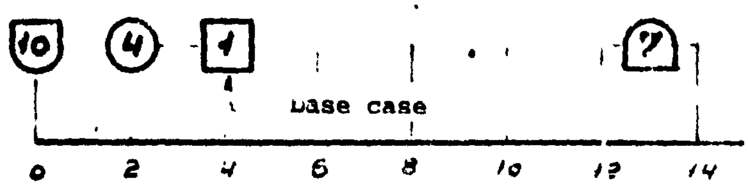
CHANGE IN SPIN TYPE AS A FUNCTION OF THE CROSS-SECTIONAL SHAPE OF THE AFT FUSELAGE

Average incidence of stationary spins

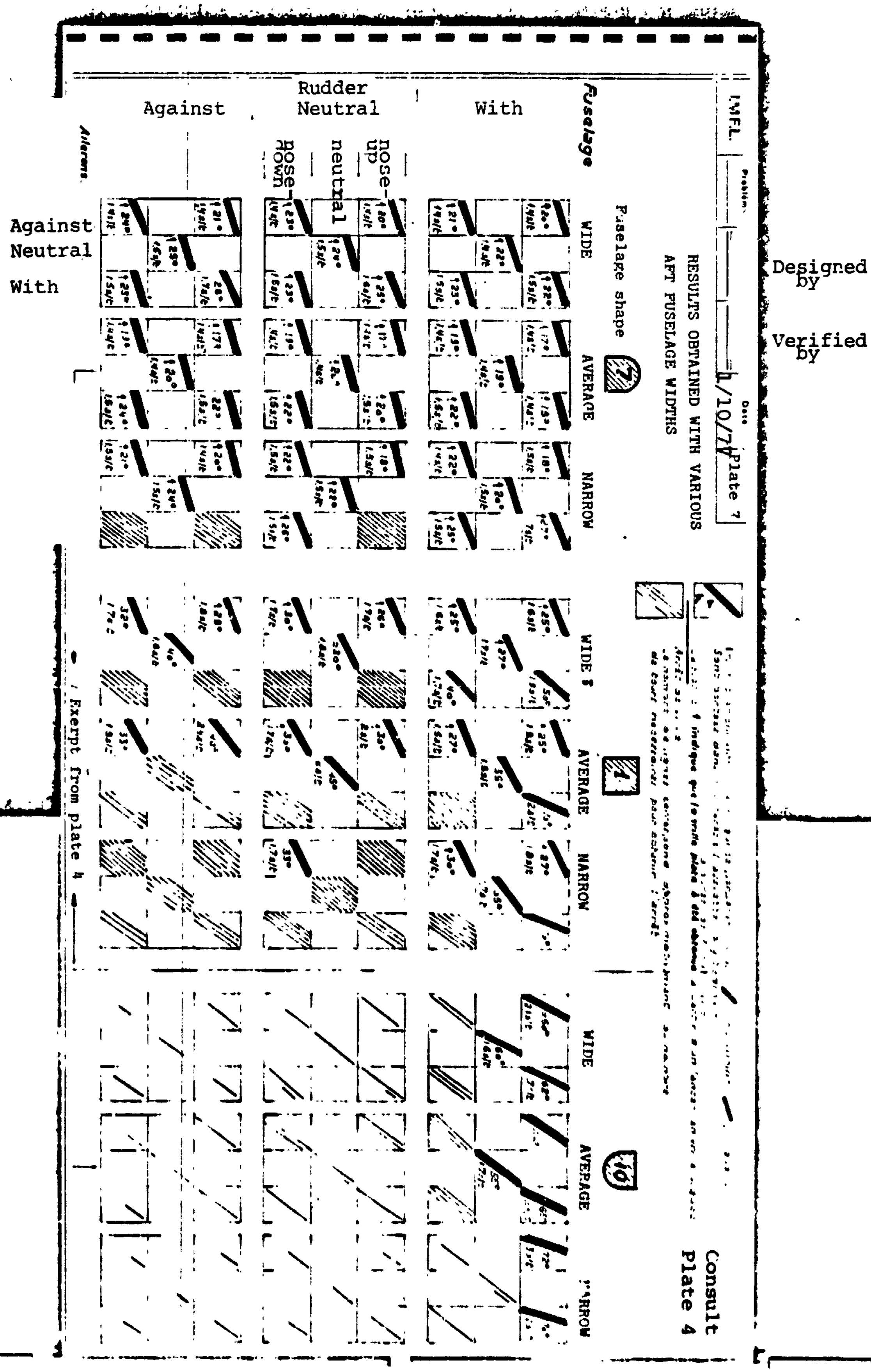


FLAT, RAPID SPIN TENDENCY

Number of control surface combinations (among the 15 tested) for which a flat spin ($10 \leq 30°$) was obtained from a launching in nose-down spin (symbol in plate 4)



The graphs in this plate are based on the results given in plate 4

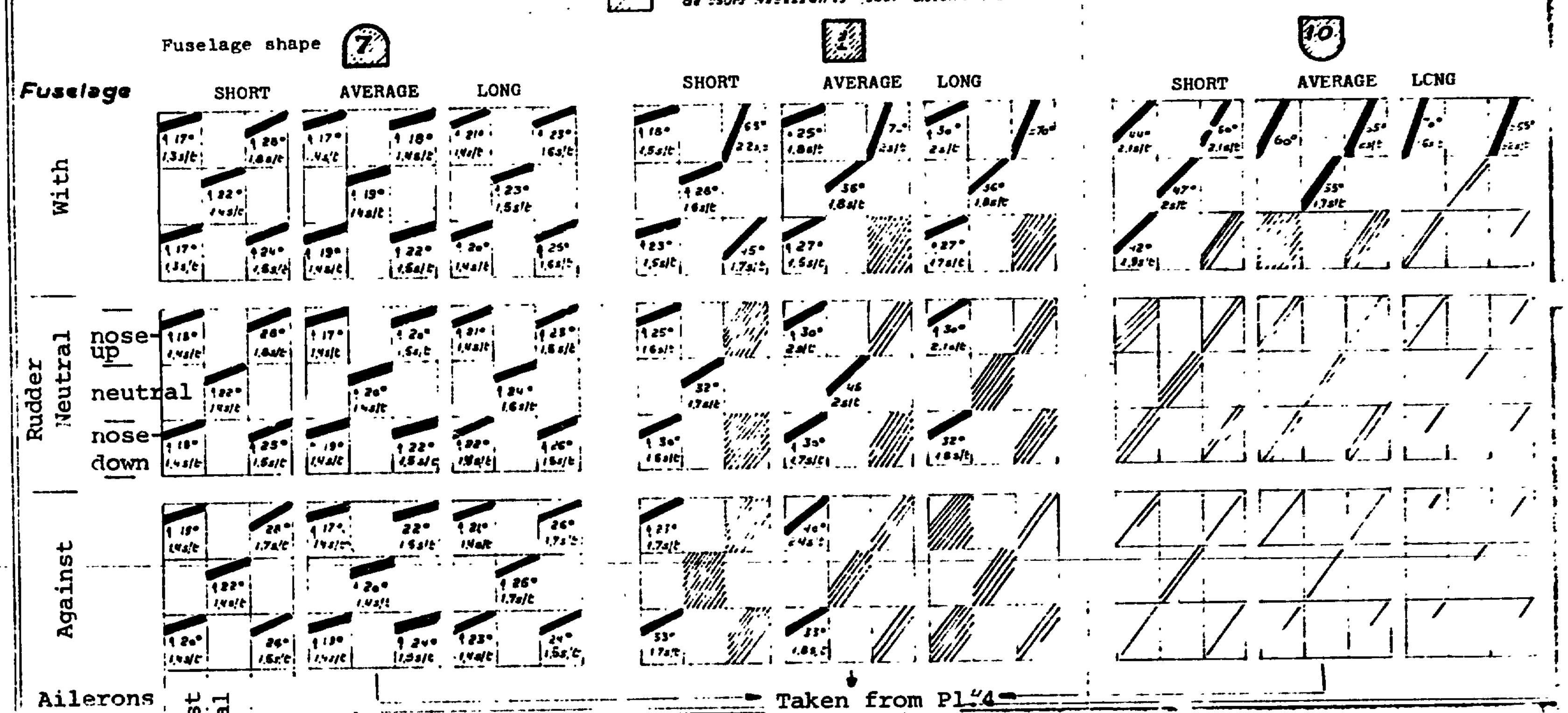


IMFL
Date 1/10/77
Plate 7
RESULTS OBTAINED WITH VARIOUS
AFT FUSELAGE WIDTHS
Fuselage shape
WIDE
AVERAGE
NARROW
Consult
Plate 4
Exerpt from plate 4
Fuselage
Ailerons
Rudder
Against
Neutral
With
nose-up
neutral
nose-down
Against
Neutral
With
Designed by
Verified by

I.M.F.L. | Problem | Designed by | Verified by | Date 1/10/77 | Plate 8

Consult Pl.4

RESULTS OBTAINED WITH VARIOUS AFT FUSELAGE LENGTHS

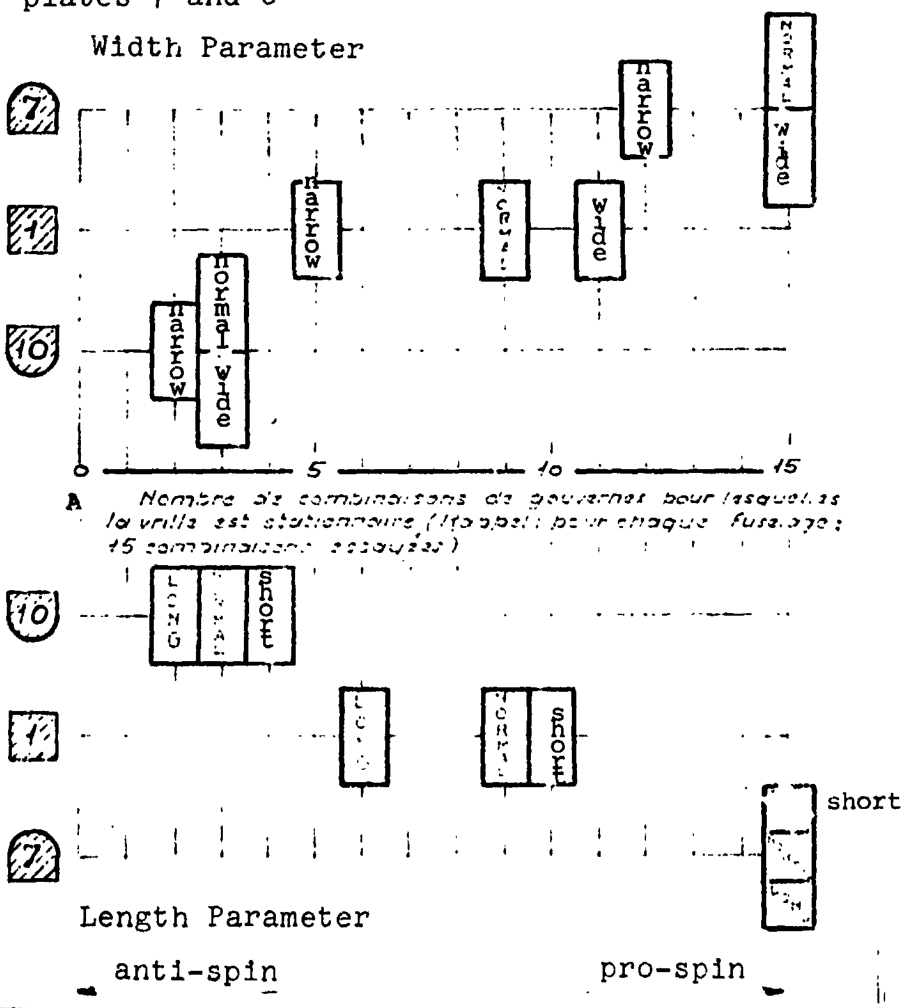


I.M.F.L.	Problem	Designed by	Verified by	Date	Plate 9
		[illegible]		1/12/77	

CLASSIFICATION OF AFT FUSELAGES
ACCORDING TO THEIR SPIN TENDENCY

Parameters considered: fuselage width and length

This plate is based on the results given in plates 7 and 8



A) Number of control surface combinations for which the spin is stationary (reminder: for each fuselage 15 combinations were tested)

I.M.F.L. | Problème | L.Bazu... | Date 1/11/77 | Plate 10

Designed by

Verified by

EFFECT OF THE VERTICAL STABILIZER ON THE SPIN

Tests with and without the vertical stabilizer

For all the tests: Ailerons Against
Control column forward

For the tests with the vertical stabilizer: rudder neutral

FUSELAGE Section	Width	Length	A. Caractéristiques de la vrille : B. AVEC DERIVE — D. Assiette Long.^{le}	E. Durée de 1 tour	C. SANS DERIVE — F. Assiette Long.^{le}	E. Durée de 1 tour (s/rev)	Vertical Stabilizer Removed
1	wide	normal	30°	1.7s/t	40°	1.8s/t	Causes nose-down spin
	narrow	"	35°	1.7s/t	56°	1.7s/t	
	Normal	"	30°	1.7 s/t	≈40°	1.9s/t	
	"	short	30°	1.6s/t	52°	1.7s/t	
	"	Long	32°	1.8s/t	47°	1.8s/t	
2	Normal	Normal	32°	1.8 s/t	≈45°	1.8s/t	
3	"	"	30°	1.7s/t	≈45°	1.7s/t	
4	"	"	28°	1.5s/t	≈50°	1.8s/t	
5	"	"	20°	1.5s/t	≈35°	1.8s/t	
6	"	"	20°	1.5 s/t	≈18°	1.4s/t	little effect
7	wide	Normal	23°	1.9s/t	23°	1.3s/t	either little effect or nose-down spin
	narrow	"	22°	1.5s/t	43°	1.7s/t	
	Normal	"	19°	1.4s/t	≈15°	1.3s/t	
	"	short	18°	1.4s/t	35° 17°	1.7s/t 1.3s/t	
	"	Long	22°	1.4s/t	22°	1.5s/t	
8	Normal	Normal	37°	2s/t	≈55°	1.7s/t	nose-down spin
9	"	"	No spin		≈60°	1.5s/t	often causes a spin
10	wide	Normal	no spin		62°	1.6s/t	
	narrow	"	no spin		no spin		
	Normal	"	no spin		≈60°	1.5s/t	
	"	short	no spin		62°	1.3s/t	
	"	Long	no spin		60°	1.4s/t	

A) Characteristics of the spin:

B. With vertical stabilizer C. Without vertical stabilizer

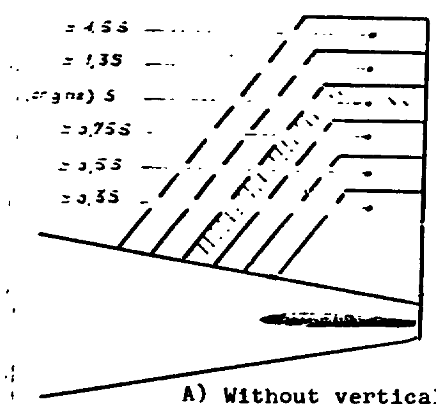
D. Longitudinal Attitude E. Duration of 1 revolution F. Longitudinal Attitude

I.M.F.L.	Problème	Designed by	Verified by	Date 1/12/77	Plate 11

EFFECT OF VARYING THE SURFACE AREA OF THE VERTICAL STABILIZER (ON A MODEL EQUIPPED WITH SHORT FUSELAGE 1)

STUDY OF THE SPIN AND PULL OUT

Vertical stabilizers tested



A) Without vertical stabilizer

B) Original vertical stabilizer

C) 1.6S Vertical stabilizer

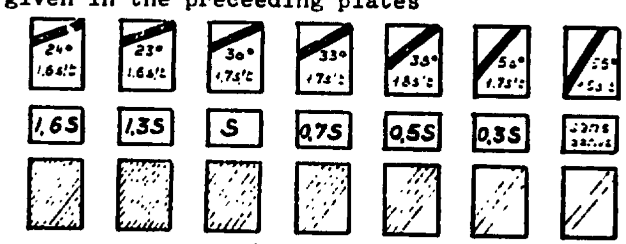
Rudder and elevator set at Neutral

For the symbols used below see the explanations given in the preceeding plates

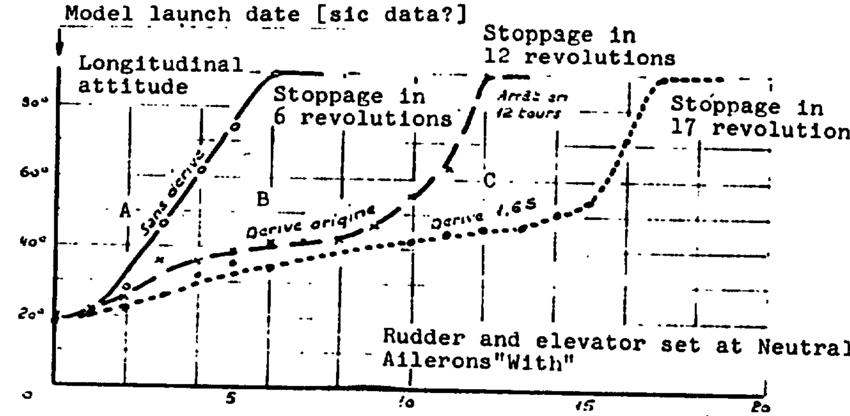
Ailerons Against

Vertical Stabilizer

Ailerons With



STUDY OF THE PULL OUT STARTING WITH A FLAT RAPID SPIN



42

I.M.F.L.	Problème	Designed by	Verified by	Date 1/14/77	Plate 12

For the tests with vertical stabilizer and horizontal stabilizer the rudder and elevator are set at neutral

RESULTS OBTAINED FOR VARIOUS FUSELAGE AND HORIZONTAL STABILIZER GEOMETERIES

See the geometry of vertical stabilizers, plate 11

Tests with various vertical stabilizers

with / without vertical stabilizer and horizontal stabilizer

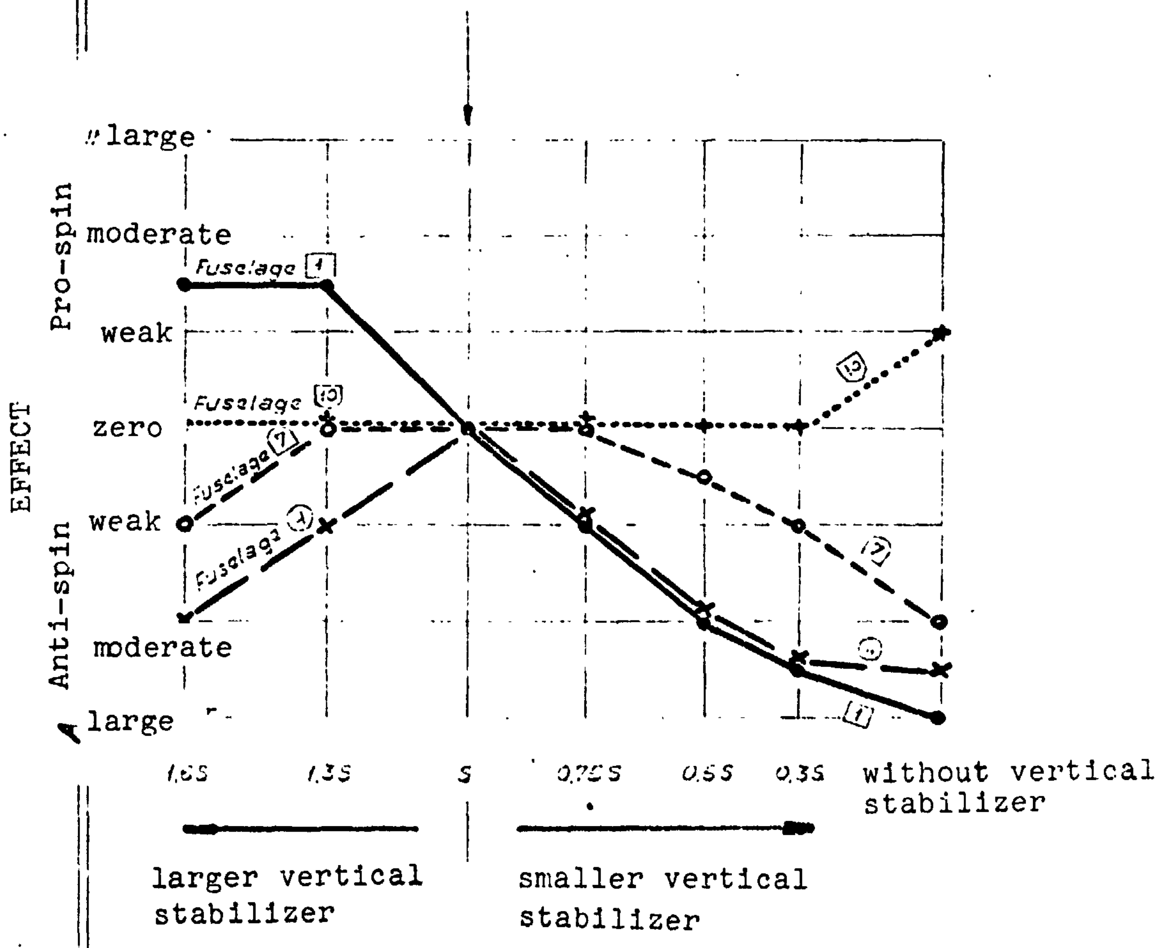
FUSELAGE	AILERONS	Vertical Stabilizer 1,6S	1,3S	S	0,7S	0,5S	0,3S	sans derive	Vertical stabilizer "S" without horizontal stabilizer	Without vertical and horizontal stabilizer
1	Against	24° 1,6 s/t	23° 1,6 s/t	30° 1,7 s/t	33° [illegible]	38° 1,8 s/t	50° 1,7 s/t	55° 1,5 s/t	≥25° ≥3 s/t	≥25 ≥3 s/t
	With	Taken from Pl 11							≥25° ≥3 s/t	≥25° ≥3 s/t
4	Against	46° 2,1 s/t	40° 1,8 s/t	34° 1,7 s/t	40° 1,9 s/t	47° 1,8 s/t	50° 1,6 s/t	55° 1,5 s/t	≥46° ≥5 s/t	35° 3 s/t
	With								≥42° 6 s/t	40° 3,5 s/t
7	Against	21° 1,6 s/t	20° 1,5 s/t	19° 1,4 s/t	19° 1,4 s/t	18° 1,4 s/t	18° 1,3 s/t	25° 1,5 s/t	18° 2,3 s/t	7° 1,4 s/t
	With		23° 1,6 s/t	23° 1,6 s/t	22° 1,5 s/t	[illegible]				12° 1,5 s/t
10	Against	Pas de vrille A	Pas de vrille	Pas de vrille	Pas de vrille	Pas de vrille	Pas de vrille	67°	Pas de vrille	40° 4 s/t
	With	-	-	-	-	-	-		-	40° 4 s/t

A) No spin

I.M.F.L.	Problème	Designed by	Verified by	Date	Plate 13
				1/17/77	

INFLUENCE OF VERTICAL STABILIZER DIMENSIONS ON THE SPIN

Basic case: original vertical stabilizer



The above graph is based on the results given in plate 12